Annual Project Summary Report

Probabilistic Liquefaction Potential and Liquefaction-Induced Ground Failure Maps for the Urban Wasatch Front: Collaborative Research with University of Utah, Utah State University and Utah Geological Survey

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Non-Technical Summary Report

When earthquake ground motion causes liquefaction in saturated, loose sands and non-plastic silts, severe damage and ground failure can occur including: flow failure, lateral spreading, bearing capacity failure, differential settlement and ground oscillation. Thus, identifying liquefiable areas is crucial to avoid these hazardous areas or to implement design and construction measures to eliminate or reduce the ground failure potential. To this end, the University of Utah has collected data for liquefaction analysis for the Salt Lake Valley, Utah and has written routines in ArcGIS to create probabilistic liquefaction hazard and lateral spread maps for use in planning and community development.

Investigations Undertaken

This project consists of collecting geotechnical and geological data in order to map the probability of liquefaction, lateral spread and ground settlement damage induced by liquefaction for the northern part of Salt Lake County, Utah. The results to be completed in this first phase of the project include: (1) a database with geotechnical data for the Northern Salt Lake County, (2) computer routines to calculate the probability of liquefaction from the data collected, (3) computer routines to calculate the probability of lateral spread and (4) probabilistic liquefaction hazard maps for the northern part Salt Lake County using the results of steps (1) and (2). Sufficient data has been collected to produce the maps; however, as more data are available, they will continue to be added to the dataset in order to produce better results. The study region for this pilot project is shown in Figure 1.

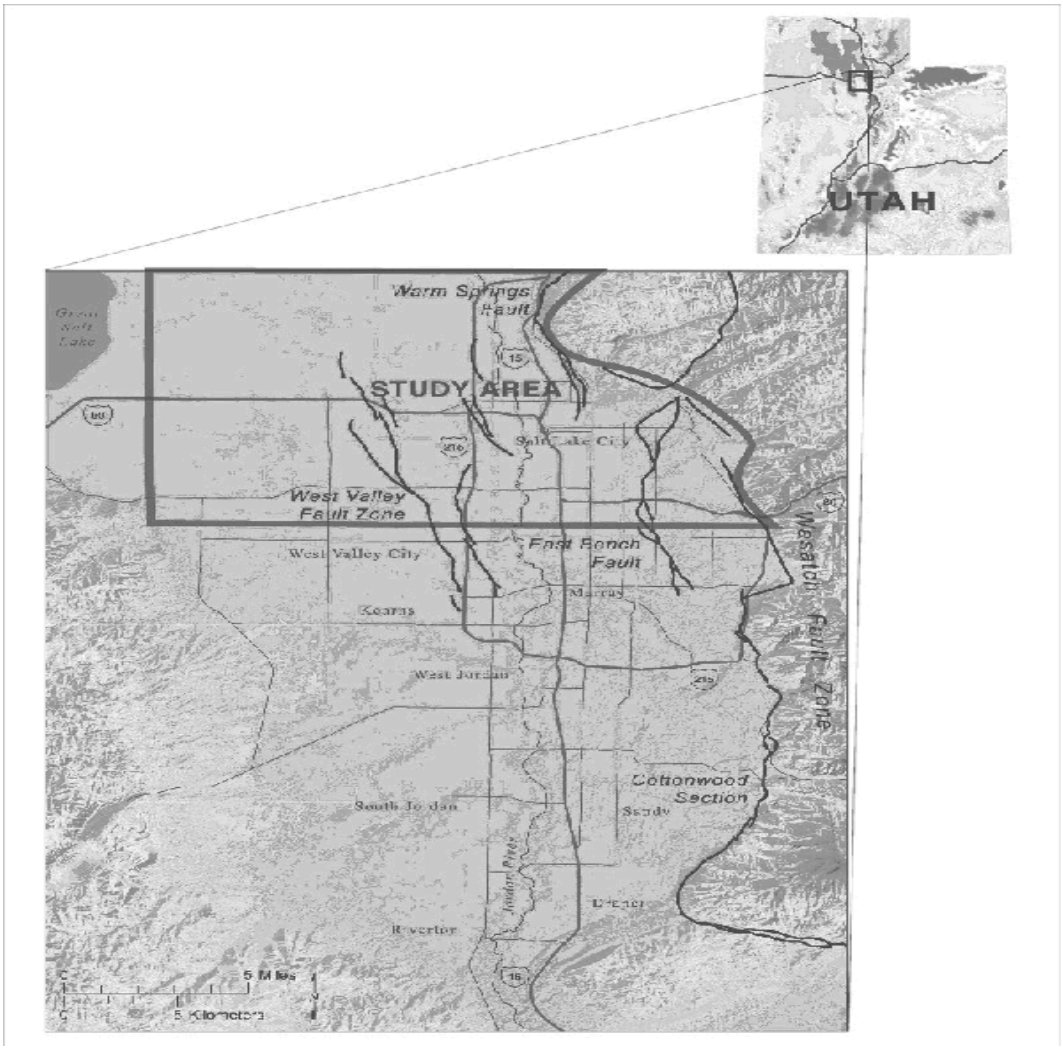

Figure 1. Map of Northern Salt Lake County with proposed study boundaries.

A Microsoft Access® database was created to store the data so that it could be readily processed. The database consists of two main tables: a SITE table and a BLOW table. The database has been structured with the same field names as the COSMOS geotechnical database for compatibility with other mapping projects being undertaken in other states. Tables showing the structure of these tables can be found at the ULAG website listed above.

The SITE table contains information about each borehole site including important parameters such as location, depth to groundwater, type of drilling and sampling equipment used, and information regarding the source of the data. One field of the database contains a hyperlink to the PDF file, which is a scanned image of the original log, so that the inputted data can be compared to the original log, if so desired.

The BLOW table contains amongst other things, the standard penetration test (SPT) blow count, or N-value. Other properties include: depth of sample, type of sample, sample unit weight, fines content and Atterberg limits, where provided. This table is linked to the SITE

database through a relationship with the SITEID field in the SITE and BLOW tables. This table also includes data qualifier fields, which qualitatively rank the data from 1 to 3. A "1" rank is given to that data that was collected and recorded properly on the soil log, a "2" rank is given to data that must be estimated from a nearby borehole logs, and a "3" rank denotes data that must be estimated from another sources, or typical values have been used. Its structure is also posted on the ULAG website.

Other data tables that were placed in the database, but could exist separately are the shear wave velocity (VS) table, the footnote table, and the typical values table. The shear wave velocity table contains the averaged shear wave velocity measurements in the upper 12 meters of the soil profile (i.e. VS_{12}). This measure is needed to complete the liquefaction analysis and VS measurements were obtained from the data gathered by the Utah Geological Survey (UGS). The footnote table contains information regarding data sources, when data were obtained from nearby boreholes, rather than from the subject borehole. The typical values table contains values and averages that will be used in the analysis, when no data was available for the subject borehole or particular sampling depth. These typical values are needed so that the liquefaction computations can be completed.

Because the mapping project uses both geological and geotechnical data to produce the final maps, it was important to correlate the geotechnical data with the mapped geological units. A scanned image of geological map (Personius and Scott, 1992) and the available data points were plotted in ArcGIS, so that the data could be assigned to its respective geological unit. This plotting also assisted in ensuring that the various geological units were adequately represented in the data collection. However, there are a few geological units where the data is scarce in comparison to others. Fortunately, this data is not as important to the analysis because the groundwater is too deep to allow liquefaction in these areas.

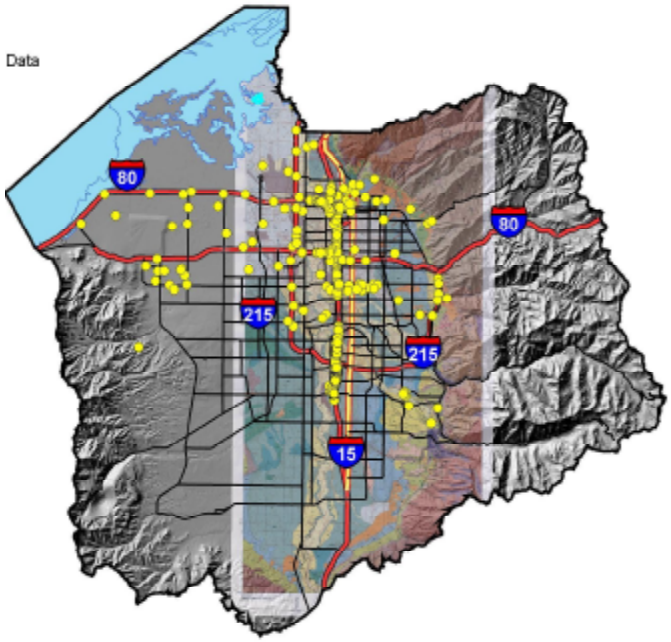

Figure 2. Borehole locations where SPT data has been collected.

Several sources were used to obtain data for this pilot project. Data of previous liquefaction studies done for Salt Lake County were obtained. The Utah Department of Transportation (UDOT) borehole data has been extensively used as well. This data came from I-80 and I-215 construction projects. The I-15 project data was available in electronic format (GINT® Database). The Anderson et al. (1994b) logs from previous liquefaction mapping efforts were obtained from the UGS and used to fill in gaps where there were limited available subsurface data.

In addition to the SPT data, cone penetrometer test (CPT) data from the I-15 Reconstruction Project is also included in the SITE and BLOW databases. This data will be used in the analysis and will be correlated with the SPT data using paired SPT and CPT data found along the I-15 corridor. Thus, any potential bias can be estimated between the two types of data.

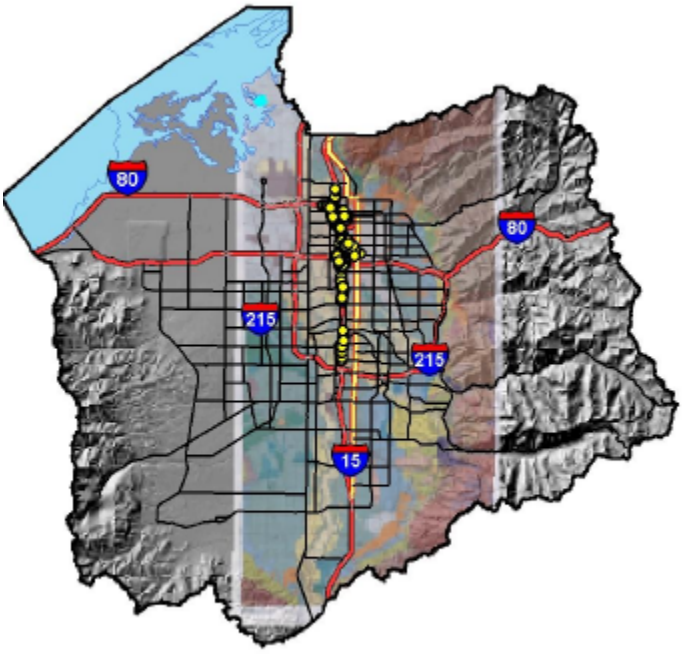

Figure 3. CPT Data locations collected for the liquefaction analysis.

For the lateral spread calculations, elevation data for the Salt Lake Valley was required to calculate the ground slope (Bartlett and Youd, 1992). This data was obtained from the National Elevation Dataset hosted by the USGS. By having a continuous data grid, slopes could be calculated at the borehole locations. The best available grid for the region was the one-third arc second grid contained data girded at a 9 meter spacing. For the free face lateral spread model (Bartlett and Youd, 1992), a GIS shape file was obtained from the Automated Geographic Regional Council (AGRC) that contained the geographic information of various rivers and canals in the Salt Lake Valley. A depth field was added to the shape file so that the routines could read off the average depth of that feature and use that in calculating the free face value, W, used in the free face model of the regression equation (Bartlett and Youd, 1992). We are currently in the process of collecting flood plain data for the depths of those features in Salt Lake County.

To obtain the necessary VS_{12} measurements, the data from the UGS was plotted spatially. Then, using a routine developed for ArcGIS, VSFinder, each borehole was assigned a VS_{12} measurement based on the nearest measurement within the same geological unit.

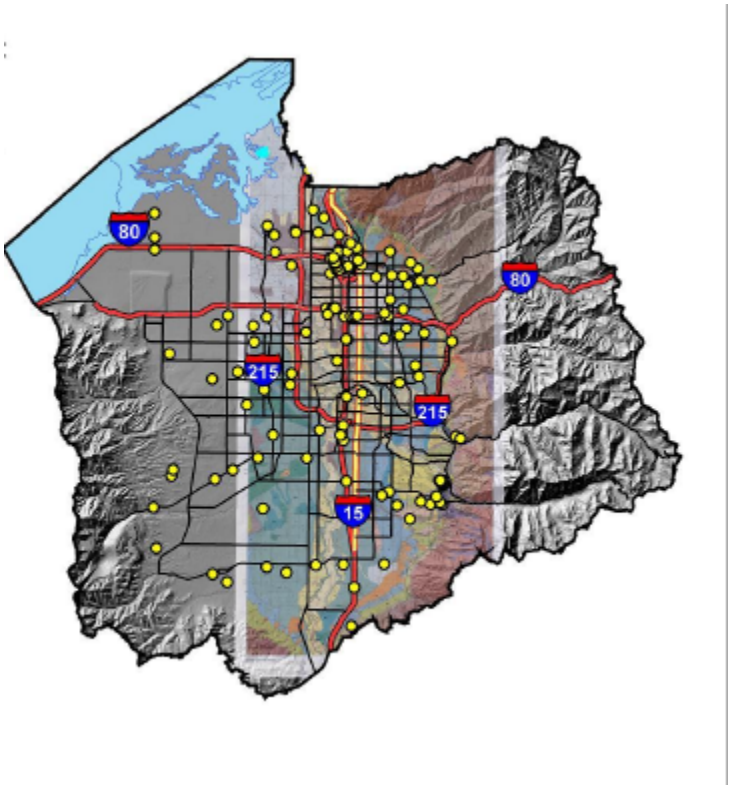

Figure 4. Shear wave velocity measurement locations.

Other routines developed in ArcGIS include the SlopeFinder routine. This routine first finds the local ground slope at a point obtained from a slope grid created using the 3D Analyst toolbar in ArcGIS. It then queries the digital elevation model to find the elevations at the various grid points up to a distance of 200 meters from the borehole. It then calculates the slope from that point to the borehole. The maximum slope is returned, and will be used for the lateral spread analysis.

To better coordinate our research with that being done by Utah State University and the UGS, we have held several working meetings. The first of which was in February 2004 with the Utah Liquefaction Advisory Group (ULAG). Here we discussed the development of the database and how data would be collected. In July of 2004, we met with Mark Peterson (USGS) and received his input on the maps and considerations that should be taken into account when developing the maps including the importance of making the maps easily understood by the public. In October 2004, we met with Dr. Raymond Seed (University of California at Berkeley) to get his input on the liquefaction analysis. In this meeting, it was decided that CPT data should be used as part of the project. In addition, it was recommended that further analysis of the liquefaction potential of clayey sediments should be conducted, and that the pga curves should be modified from the rock site estimates to soil estimates by soil amplification curves developed by Seed et al. (2001).

Results

Collection of data has been fruitful along the Wasatch Front. Currently the database consists of approximately 600 boreholes, as shown in Figure 1. In addition, the data from approximately 350 CPT drill tests have been added to the database. The coverage of this data is shown in Figure 3.

To assist in data processing, routines are being written to calculate corrected blow count ($N1_{(60)}$) values and effective stresses used in the liquefaction analysis. Routines are also being written to develop averages of various soil parameters for in the various geological units.

Before the first map is created in early 2005, liquefaction routines developed by Utah State University need to be completed. Once these routines are written, the database will be processed and the probability of liquefaction will be returned at each point where there is borehole data. These will be then compared with the geological units and the maps will be produced and distributed to the community.

Reports published

There have been no reports published as of present for this project.

Data Availability

The data collected on the project has been posted to the website http://www.civil.utah.edu/~bartlett/ulag.html. The data is in Microsoft Access® format and is readily available for download. The structure is as described above. The data in this database has not undergone any processing. It includes the raw SPT data inputted from the soil logs, for the electronic CPT data, and the shear wave velocity data to be used in the analysis. Efforts have been taken to ensure that the original source of the data can be found for comparison. These will later be made available as PDF files.

Questions regarding the data collected can be answered by:

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References

Anderson, L.R., Keaton, J.R., Spitzley, J. and Allen, A., (1986a). "Liquefaction potential map for Salt Lake County, Utah", Final Report to the U.S. Geological Survey", May.

Anderson, L.R., Keaton, J.R., Bay, J.A., (1987). "Liquefaction potential map for the Northern Wasatch Front, Utah", Final Report to the U.S. Geological Survey".

Anderson, L. R., Keaton, J. R., and Eldredge, S. N., (1994b). "Liquefaction-potential map for a part of Salt Lake County, Utah: Utah Geological Survey Public Information Series 24, 1 sheet, 1:300,000.

Ashland, F., and Rollins, K. (1999). "Unpublished geotechnical and shear wave velocity database for the Salt Lake Valley, Utah Geological Survey.

Bartlett, S. F., and Youd T. L. (1992). "Emprical Analysis of Horizontal Ground Displacement Generated by Liquefaction-Induced Lateral Spreads," Technical Report NCEER-92-0021, National Center for Earthquake Engineering Research.

Dames and Moore, (1996a). "Geotechnical Report for the Reconstruction of Structures and Embankments 600 South Section I-15 Corridor From 600 South to 960 South," UDOT Contract No. SP-15-7(129)310, Station 31+275 to 32+420, Salt Lake City, Utah, Sept. 1996.

Dames and Moore, (1996b). "Geotechnical Report for the Reconstruction of Structures and Embankments 1300 South Section I-15 Corridor," UDOT Contract No. SP-15-7(132)308, Station 29+300 to 31+275, Salt Lake City, Utah, Sept. 1996.

Dames and Moore, (1996c). "Geotechnical Report for the Reconstruction of Structures and Embankments 2400 South Section I-15 Corridor," UDOT Contract No. SP-15-7(1287308, Station 26+800 to 29+300, Salt Lake City, Utah, Sept. 1996.

Davis, F.D., 1983, Geologic map of the central Wasatch Front, Utah: Utah Geological and Mineral Survey Map 54-A, scale 1:100,000.

FEMA (1999). Federal Emergency Management Agency, "HAZUS 99 Technical Manual," Vol. 1.

Keaton, J. R., and Anderson, L. R. (1995). "Mapping Liquefaction Hazards in the Wasatch Front Region: Opportunities and Limitations," Environmental and Engineering Geology of the Wasatch Front Region, Utah Geological Association Publication, 24, 1995.

Kleindfelder, Inc. (1996a). "Preliminary Geotechnical Exploration Report," I-15 Corridor Reconstruction Section 4, 600 South, Project No. SP-15-7(129)310, Station 32+080 to 35+044, Salt Lake City, Utah, Sept. 1996.

Kleindfelder, Inc. (1996b). "Geotechnical Exploration Report," I-15 Corridor Reconstruction Section 9, State Street, Project No. SP-80-3(41)125, Station 1+220 to 1+687, Salt Lake City, Utah, Sept. 1996.

Kleindfelder, Inc. (1996c). "Geotechnical Exploration Report," I-15 Corridor Reconstruction Section 8, 3300 South, Project No. SP-15-7(144)305, Station 28+600 to 24+500, Salt Lake City, Utah, Sept. 1996.

Kleindfelder, Inc. (1996d). "Geotechnical Exploration Report," I-15 Corridor Reconstruction Section 10, 900 W., Project No. SP-020(1)17, Station 1+000 to 10+640, Salt Lake City, Utah, Sept. 1996.

Liao, S. S. C., Veneziano, D., and Whitman, R. V. (1988). "Regression models for evaluating liquefaction probability," Journal of Geotechnical Engineering, ASCE, Vol. 112, No. 1, pp. 44-59.

Miller, R.D., 1980, Surficial geologic map along part of the Wasatch Front, Salt Lake Valley, Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF-1198, scale 1:100,000.

NCEER (1997). "Proceedings of the NCEER Workshop on Evaluation of Liquefaction Resistance of Soils," edited by Youd, T. L., and Idriss, I. M., Technical Report NCEER-97-0022, National Center for Earthquake Engineering Research.

NEHRP (1997). "NEHRP Recommend Provisions for Seismic Regulations for New Buildings and Other Structures," 1997 Edition Part 1: Provisions (FEMA 302), prepared by the Building Seismic Safety Council for the Federal Emergency Management Agency, Washington, D.C.

Personius, S.F., and Scott, W.E., 1992, Surficial geologic map of the Salt Lake City segment and parts of adjacent segments of the Wasatch fault zone, Davis, Salt Lake, and Utah Counties, Utah: U.S. Geological Survey Miscellaneous Investigations Map I-2106, scale 1:50,000.

Seed, R. B., Cetin, K. O., Moss, R. E. S., Kammerer, A. M., Wu, J., Petana, J. M., Riemer, M. F. (2001). "Recent Advances in Soil Liquefaction Engineering and Seismic Site Response Evaluation," Fourth International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics, University of Missouri-Rolla, Rolla, Missouri, 2001, 45 pages, Paper No. SPL-2.

Tooker, E.W., and Roberts, R.J., 1971, Geologic map of the Magna quadrangle, Salt Lake County, Utah: U.S. Geological Survey Geologic Quadrangle Map GQ-923, scale 1:24,000.

Youd, T.L., Hansen, C.M., Bartlett S.F., 2002, "Revised Multilinear Regression Equations for Prediction of Lateral Spread Displacement," Journal of Geotechnical and Environmental Engineering, December 2002, p. 1007-1017.

Youd, T. L., and Perkins, D. M. (1978). "Mapping Liquefaction-Induced Ground Failure Potential," Journal of the Geotechnical Engineering Division, ASCE, Vol. 104, No. GT4, April, 1978, pp. 433-446.